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AIRFIELD PAVEMENT DESIGN OF THE CORPS OF ENGINEERS

by Gayle McFadden, M. ASCE

AIR TRANSPORT DIVISION

{Discussion open until November 1, 1954}

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AIRFIELD PAVEMENT DESIGN OF THE CORPS OF ENGINEERS

Gayle McFadden,[1] M. ASCE

It will be noted that the title of this paper qualifies "Airfield Pavement Design" by the phrase "Of the Corps of Engineers." The use of this phrase was deliberate since there are other methods of design in current use, and it was not desired to mislead the reader into thinking that the methods described herein were the standards to the exclusion of all others.

The development of airfield pavement design has shown a vast amount of progress during the last decade. It goes without saying that this development of pavement design has necessarily followed the changing trend of airplane design. It will be recalled that ten to twelve years ago airfield pavements were being designed for both commercial and military airplanes having a maximum gross operating weight of approximately 25,000 pounds. The commercial airplanes have steadily increased in weight until today we have the modern stratocruiser with a gross weight of approximately 140,000 pounds. The military airplanes have gone through an even greater transition with the gross weight of the present super bomber exceeding 300,000 pounds. In addition, the advent of the jet and rocket propelled airplanes and high-pressure tires has added to the complexity of the design problem.

This changing trend has produced an evolution of design from where it was feasible to extrapolate standard highway practice for the lighter wheel loads to the development of the specialized field of airfield pavement engineering. This development was brought about by both the heavier loads and the change in operating characteristics from highway usage.

At the time the Corps of Engineers took over responsibility for Air Force construction, the problem of selecting not only an adequate design but one that was susceptible of meeting the changing trend of airplane design and usage was soon apparent. The major factors in making this selection appeared to be (1) assurance of adequately designed pavements, (2) elimination of a wide variety of designs based on a wide variety of diverse opinions, (3) limiting the use of or eliminating entirely unproven theoretical design methods, (4) providing a uniform design procedure in order that pavements built anywhere could be evaluated quickly in terms of load-carrying capacity and other operating requirements, and (5) securing a basis for further development of design methods through the application of data obtained by future investigation and actual service behavior of pavements. In addition, the requirements of the theater engineer for simplicity and mobility of equipment used with the design procedures had to be kept in mind.

Design procedures of the Corps of Engineers for rigid type pavement follow the general pattern of most other designers of that type pavement. This procedure is, basically, that devised by the late Dr. H. M. Westergaard. Most State Highway Departments, the U.S. Navy, and the Portland Cement

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Association use this same general design procedure with some minor deviations in application. This procedure expresses concrete slab thickness in terms of four principal factors: (1) type of aircraft gear, (2) gear design load, (3) subgrade or base course modulus, and (4) concrete flexural strength. The design curves illustrated by Figs. 1A through 4A have been determined by empirical means on the basis of full scale investigations to date, supplemented by consideration of theoretical analysis. Design curves are in line with theory in that they indicate less required thickness of pavement for the higher values of concrete flexural strength and subgrade modulus.

Fig. 6 illustrates a design, without considering the effect of frost action, using a dual wheel landing gear with wheels spaced 37.5 inches center to center, a design load of 90,000 pounds on the gear, a K value of 100, and concrete with a flexural strength of 650 psi at the age of 90 days. Using these design assumptions and entering the design chart illustrated in Fig. 3A, a slab thickness of 16 inches is indicated.

Subgrade reactions and concrete strength normally depend upon many influences which are difficult to evaluate. It is necessary when selecting values for use in design to study all applicable previous tests on representative soils and concrete and to consider all reliable information concerning past performance of similar construction. All such previous tests and experience are considered as supplementing rather than substituting for primary testing. The Corps of Engineers does not usually consider a subgrade value in excess of 300 K for design purposes. This is because it is considered improbable that a uniform value in excess of this figure can be found or obtained in the average construction project. In some instances, this figure has been exceeded but only after a careful study of each situation. In the case of the evaluation of the load-carrying capacity of old pavements, a K value of 500 to 600 has been accepted where it was found that uniformity had been obtained after some years of use. An investigation is underway to determine the feasibility of increasing the allowable K value for design, and at its present stage there is an indication that the limit can reasonably be raised to 500. Until recently, the Corps of Engineers has used the flexural strength of concrete at 28 days in determining the slab thickness. Since it has been found that the full design load is seldom if ever applied at that age but would more nearly approach 90 days, this latter figure has been adopted for use in the design procedure. This will effect an economy in thickness for the heavier loadings of from one to one and one-half inches and proportional savings for the lighter loads.

It is recognized that base courses provide additional structural strength when placed beneath concrete pavements. It has been found, however, that in some instances it is more economical to increase the concrete pavement thickness rather than provide a base course for structural advantage. There are exceptions to this concept in designing pavements over pumping soils and those susceptible to frost action.

The Corps of Engineers recognizes, as do most other designers, that joints in rigid type pavements are the most troublesome feature and is conducting investigational projects with a view of taking corrective measures wherever practicable. Expansion joints except at structures and intersections have been placed farther apart than formerly. At the present time, the interval is about 400 feet throughout large paved areas, as runways, aprons, or long taxiways, with slab thickness less than 10 inches. Regularly spaced expansion joints, both longitudinal and transverse, are omitted in pavements 10 inches or more thick unless the concrete is composed of aggregate particles which have high-temperature coefficients of expansion. Construction joints may be either of

the dowel or key variety provided the slab is 8 inches and greater in thickness. Slabs of less than 8 inches must have doweled joints. Contraction or weakened plane (dummy) joints may be either of the formed or sawed type. The sawed joint may be considered somewhat in the experimental stage for airfield pavements. However, their advantages in installation and the riding qualities of the pavement warrant a continuation of effort to overcome the difficulty in timing the cutting of the joint and subsequent sealing which seem to be the main objection at the present time. The Corps is presently conducting studies to improve the design, construction and cost of sawed joints.

Steel is not used in rigid type pavements except as load transfer devices across construction joints of the dowel type and at expansion joints. Dowels or tie bars are not used across contraction joints, excepting for tie bars across the contraction joint in the outside lane.

The Corps of Engineers uses the California Bearing Ratio (CBR) method of design for their flexible type pavements. This method was selected after a rather comprehensive investigation of the various methods in vogue at the time. The events leading up to and the reasons for the selection of this method have been amply covered in a symposium published by ASCE[2] and therefore will not be further detailed here.

The CBR is an empirical method originated by the California Division of Highways for use in designing the flexible type highways in that state. When the method was adopted, design curves were available for wheel loads of approximately 12,000 pounds. Since the Corps was faced with an immediate need for much greater wheel loads, these curves were extrapolated to wheel loads of 60,000 pounds, tentatively adopted, and at the same time an investigational program was initiated to provide information for verifying or revising the curves. Subsequently, the investigational program was extended to establish design curves for wheel loads up to 200,000 pounds. Further studies provided information to establish curves for various landing gear configurations and tire contact pressures.

The design procedure by the empirical CBR method consists of determining, by an arbitrary penetration test, a modulus of shearing resistance of a subgrade soil or base course material and the application of the data so obtained to empirical design curves, illustrated by Figs. 1B through 4B, to determine the total pavement thickness and/or the thicknesses of the various courses. The modulus of shearing resistance as determined by the penetration test is known as the California Bearing Ratio. The ratio is expressed as a percentage of the standard stability value for crushed stone.

The design curves as illustrated have been developed by the Corps of Engineers from studies as before stated. These curves have been correlated with data from accelerated traffic tests and with data from airfield pavement service records. Until such a complete correlation is made, it is not believed that any design method can be considered as valid.

The design curves show for a given wheel (or gear) load the total thickness of stable subbase, base and pavement required above a layer of material with a given CBR. The exception to this is the thickness of high-quality base course required immediately under the bituminous surface material and the thickness of the bituminous surface itself. The base course is arbitrarily fixed, as a result of investigations, at 6 inches of crushed material having a CBR value of 80 or better where such material is economically available. Where it is not economically available, the thickness of the bituminous surface will be

2. Transactions of American Society of Civil Engineers, Vol. 115, 1950, p. 453.

increased proportionally as indicated by the curves. The bituminous surface will vary in thickness from 2 to 4 inches depending on the design load. The appropriate thickness is shown on the curves by the cut-off figures. These figures are the combined thickness of base and surface with the base having a constant thickness of 6 inches and the difference being the thickness of the bituminous surface.

Fig. 6 illustrates the design of a flexible pavement, without considering the effect of frost action, and shows the layered system and the relative value of each layer. The condition illustrated assumes a subgrade that can be compacted to a CBR value of 10 and a design gear load of 90,000 pounds on dual wheels spaced 37.5 inches center to center and equipped with tires that will be inflated to give a contact area of 267 square inches. The design curves (Fig. 3B) show that for the given load a total thickness of subbase, base and pavement above the compacted subgrade must be 25 inches. To take the maximum advantage of local (low cost) materials, a survey is made to determine their availability, and it is determined that there are economically available three types of material that will fulfill requirements. These are classified from tests as having 20, 55 and 85 CBR values. Again going to the design curves, we find that a thickness of 15 inches is required above a 20 CBR material. Deducting this figure from the total requirement of 25 inches leaves 10 inches that we may utilize as a layer for the 20 CBR material. The requirements for a pavement of this type provide a minimum of 6 inches of base course having a CBR value greater than 80 and a bituminous surface of not less than 4 inches. Therefore, of the remaining 15 inches, 10 inches is mandatory construction, leaving 5 inches which may be utilized by a layer of 55 CBR material. The 85 CBR material, having fulfilled the requirement of plus 80 CBR, is used for the 6-inch base course. For the purpose of economy, the bituminous surface is divided into two courses, a 2 1/2 inch binder course and a 1 1/2 inch wearing course. The binder course is less costly because of relaxed gradation requirement for the aggregate and a lesser bitumen content.

The design of the bituminous surface is becoming increasingly critical with increasing use of high pressure tires and jet propelled aircraft. The Corps of Engineers has developed a method of designing bituminous mixes that will permit not only uniformity and adequacy of design but control of the mix during construction. This is known as the Marshall method, named for its originator, Mr. Bruce C. Marshall.

The Marshall method is also empirical in nature and like the CBR method consists of a method and a test. The method of design will assure the selection of optimum bitumen content with accuracy and will indicate the maximum permissible amount. We believe this to be the crux of the whole thing since it is a well-known fact that the quantity of bitumen is the most important factor in a paving mixture. In the method of design, specimens are compacted under controlled effort at several bitumen contents using the proposed aggregate. These specimens are then subjected to test. In this test, the specimens are heated to a temperature of 140°F and placed in a breaking head consisting of two segments of a 4 inch inside diameter ring from which a 3/4 inch strip has been removed from each side. It should be noted that the specimen is tested in compression with the stress applied parallel rather than perpendicular to the flat faces. The load is applied at a rate of movement of 2 inches per minute until the specimen fails. The total load in pounds required to break the specimen is termed its stability. The amount the upper and lower segments of the breaking head were squeezed together in making the test is

measured in hundredths of an inch and is called the flow value. It is considered that flow is measure of the plasticity of the specimen and an indication of the potential durability of the mix.

As a result of this test, the bitumen content which gives the most desirable values for (1) unit weight total mix, (2) percent voids total mix, (3) percent voids filled with asphalt, (4) stability, and (5) flow is selected as the optimum. The first three properties are in standard usage in asphalt terminology. The other two properties are determined in the Marshall stability apparatus.

In areas where seasonal freezing and thawing to an appreciable depth occurs in the soil, the Corps of Engineers designs both rigid and flexible type pavements to resist the detrimental effects of frost action. The detrimental effects of frost action in subsurface materials are indicated by nonuniform heave of pavements during the winter and by loss of strength of affected soils with a corresponding reduction in load-supporting capacity during the spring thawing period. This is recognized by all State Highway Departments in these areas since the effects of frost action usually result in hazardous operational conditions, excessive maintenance, or pavement destruction. Highway departments have in the past usually restricted the loads permitted on these pavements during the critical period. Since it is not feasible to limit loads on airfield pavements, particularly military airfield pavements, the design is modified to provide the necessary additional requirement.

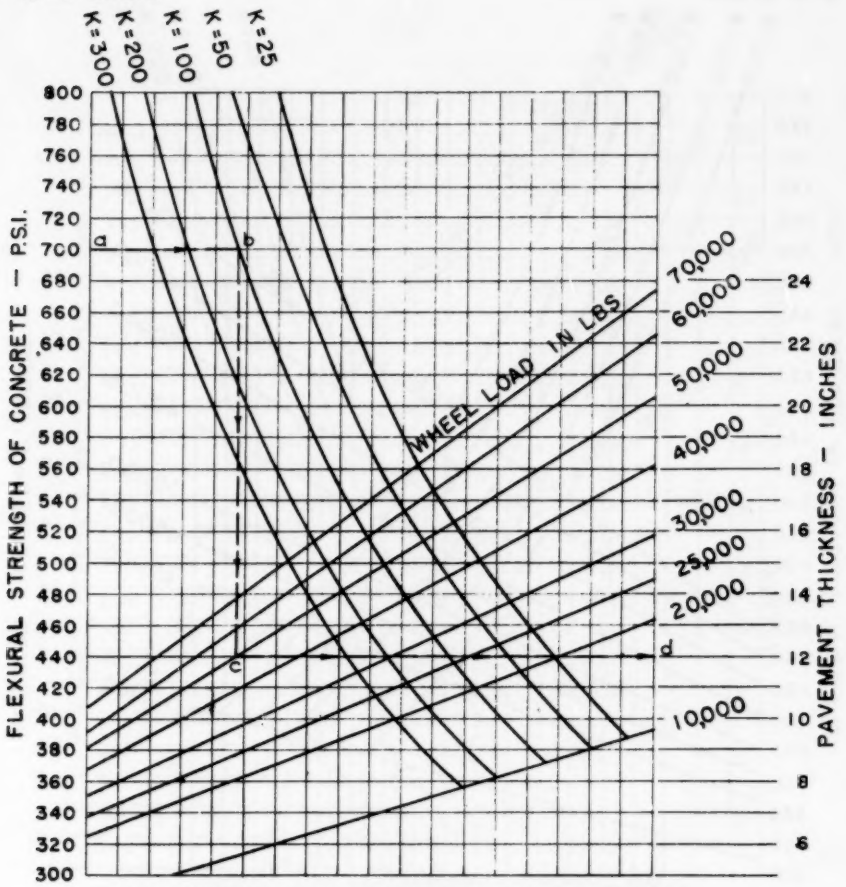
For detrimental frost action to take place, three conditions must be present simultaneously: (1) the soil must be frost susceptible, (2) temperatures must be below freezing, and (3) a source of water must be available. A frost susceptible soil is considered as one containing three percent or more by weight of grains finer than 0.02 mm in diameter. However, some soils may contain a higher percent of minus 0.02 mm without being considered frost susceptible. The Corps of Engineers has classified frost susceptible soils into four groups in order of increasing susceptibility. The freezing temperatures must penetrate the soil to an appreciable depth. The source of water may be from an underlying ground water table, from infiltration or perched water.

In order to keep abreast of the changing trend of airplane design, the Corps of Engineers finds it necessary to maintain a continuing program of investigations from which is developed data that are used in establishing pavement and other military construction design criteria. These investigations are initiated and coordinated by the Airfields Branch, Engineering Division in the Office of the Chief of Engineers, and the majority of the investigational work is done in three Corps of Engineers laboratories designated for that purpose. These laboratories are (1) the Rigid Pavement Laboratory, located in the Ohio River Division at Cincinnati, Ohio; (2) the Flexible Pavement Laboratory, located at the Waterways Experiment Station, Vicksburg, Mississippi; and (3) the Arctic Construction and Frost Effects Laboratory, located in the New England Division, Boston, Massachusetts.

These investigations have resulted in taking advantage of every possible refinement in design that could lead to better and more economical construction. The most urgent need for this type of investigation program stems from the fact that airfield pavement design being a comparatively new branch of engineering, together with the rapidly changing trend of airplane design, lacks background information available in the longer established branches. Some of the information developed results in direct savings in design and construction. Others are of a more intangible nature such as the means of pointing out to the airplane designer items, in airplane design, that if modified would effect considerable savings in construction effort and cost. Figs. 5A and 5B when

compared with Figs. 4A and 4B illustrate a combination of these two conditions. Figs. 5A and 5B are airfield pavement design curves developed several years ago for rigid and flexible type pavements, respectively. At that time pavements were designed for single wheel loads, and high pressure tires were not a problem. A single set of curves for each type of pavement sufficed. As a result of the change to multiple-wheel landing gears and refinements in design made as a result of the investigational program, four sets of curves replaced the single set and reflect the design required for different types of landing gear, tire pressure, and contact area. A comparison of these two charts, following the arrows which reflect comparable design assumptions, will show a saving in pavement thickness in the rigid type from a former 25 inches to a present 13 1/2 inches, and in the flexible type from a former 32 inches to a present 18 inches. It is emphasized that these savings reflect not only refinement in design but change in landing gear configuration. This is only one example of the result of the efforts to keep current "Airfield Pavement Design of the Corps of Engineers."

3-6-50, 2-21-51 REV.
6-13-50 REV.

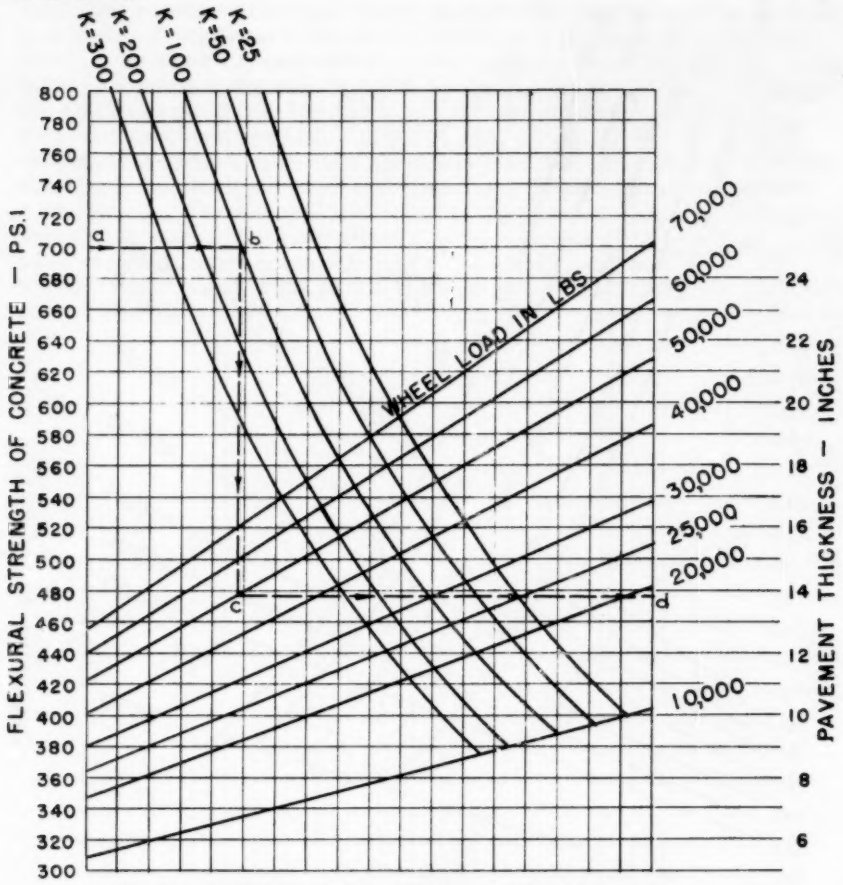


THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000FT SECTION AT EACH END)

PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. SINGLE WHEEL 100 — PSI

Fig. 1A

3-7-50, 2-21-51 REV
6-13-50 REV.

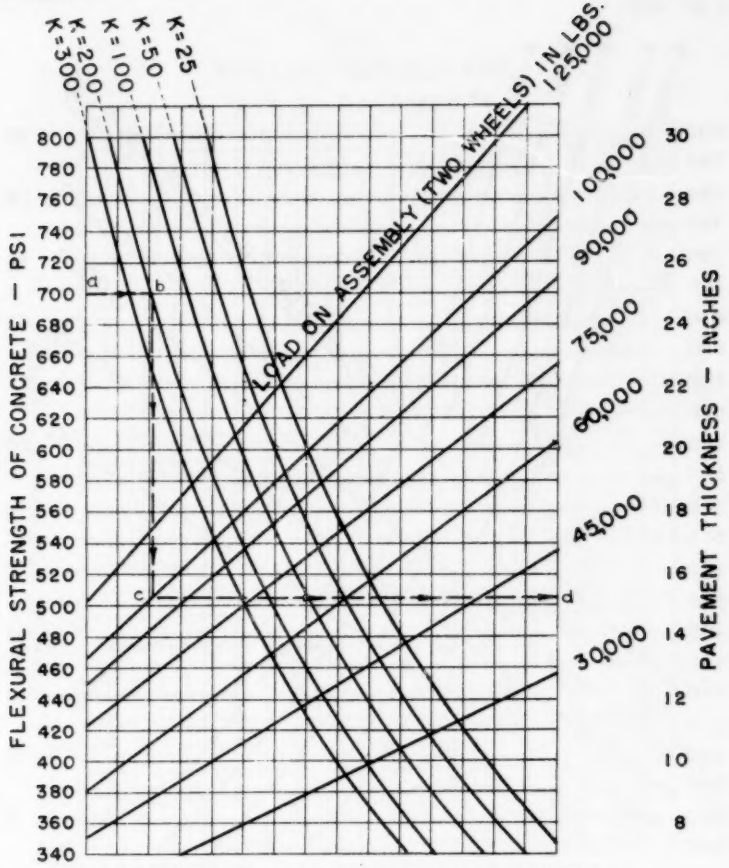


THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT. SECTION AT EACH END)

PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. SINGLE WHEEL 200 — PSI

Fig. 2A

3-10-50, 2-21-51 REV.
6-13-50 REV.

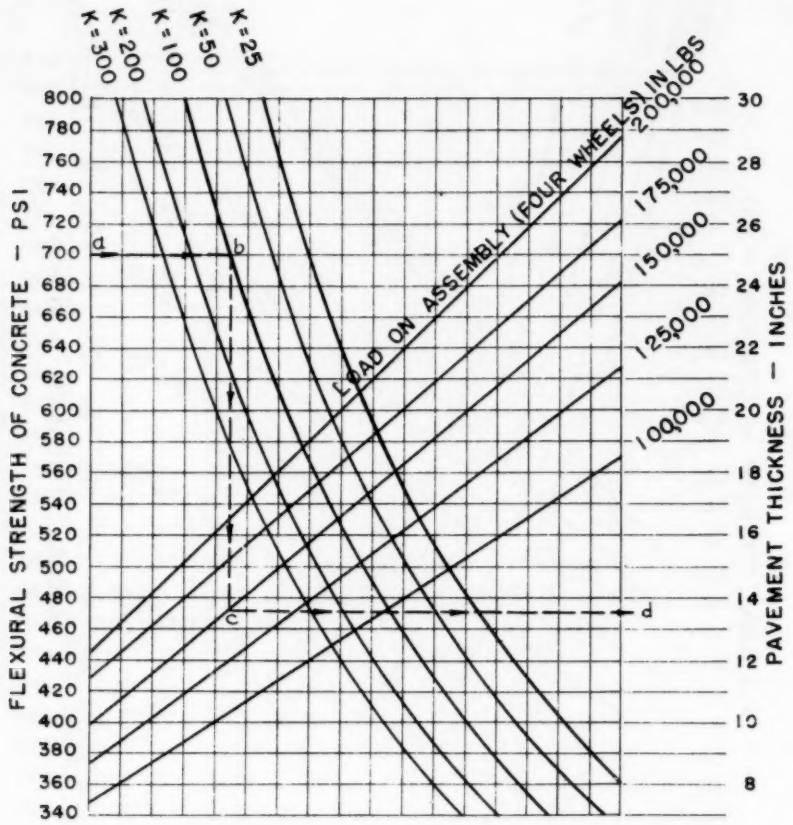


THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000FT SECTION AT EACH END)

PAVEMENT DESIGN CURVES FOR CONCRETE TAXIWAYS ETC. DUAL WHEELS SPACED 37" C.C. CONTACT AREA 267 SQ. IN. EACH WHEEL

Fig. 3A

3-8-50, 2-21-51 REV
6-13-50 REV.

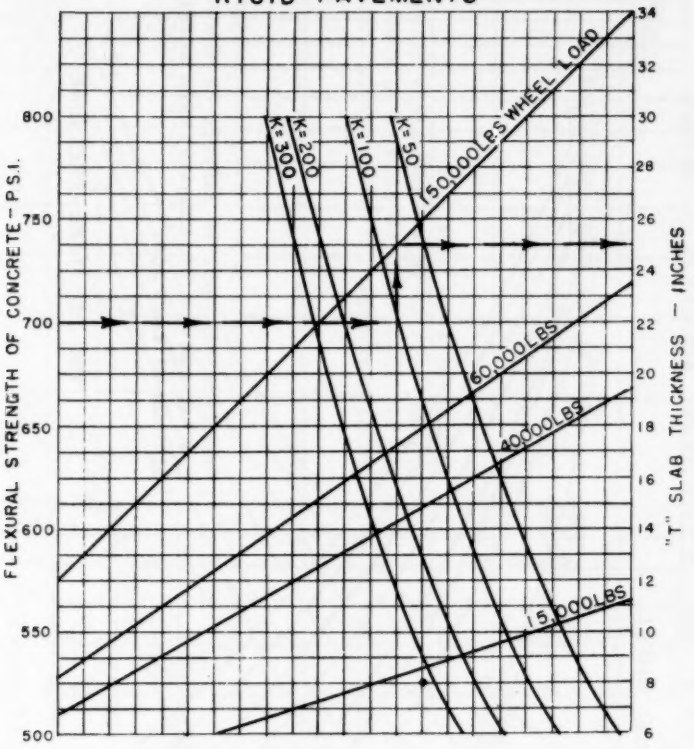


PAVEMENT DESIGN CURVES
FOR CONCRETE TAXIWAYS ETC.
TWIN TANDEM GEAR — SPACING 31" X 60"
CONTACT AREA 267 SQ. IN. EACH WHEEL

THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000FT. SECTION AT EACH END)

Fig. 4A

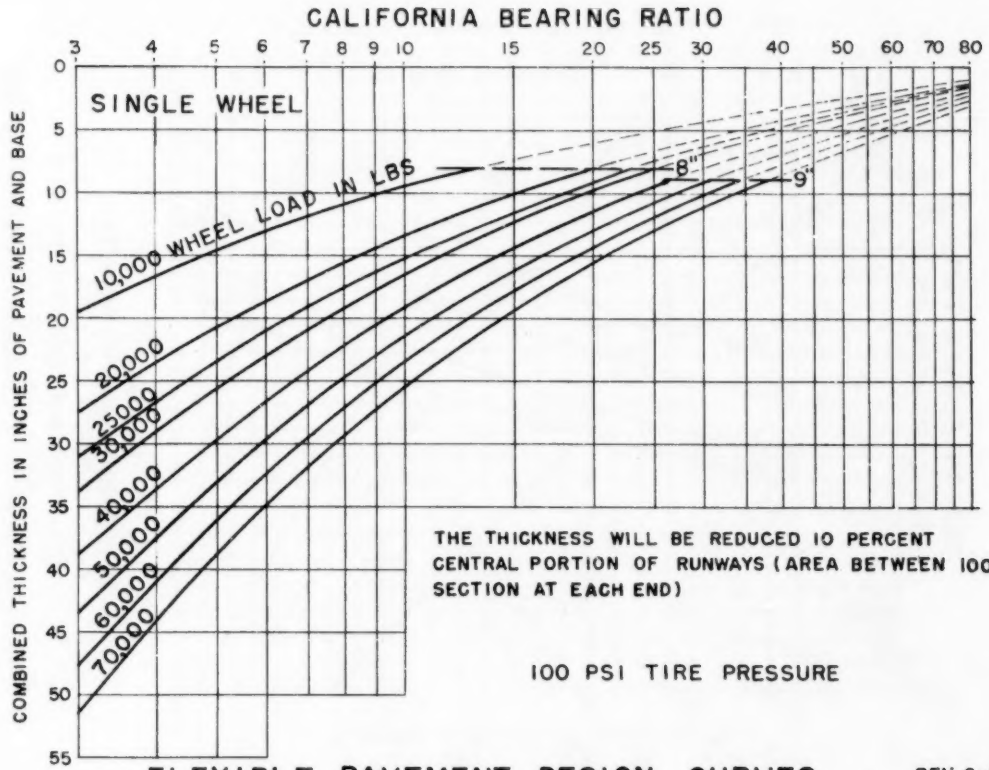
DESIGN CURVES FOR RIGID PAVEMENTS



EXAMPLE

TO DETERMINE SLAB THICKNESS "T"
GIVEN - CONCRETE P.S.I. = 700
SUBGRADE MODULUS K = 100
WHEEL LOAD = 150,000 LBS
WITH ABOVE VALUES FOLLOW DOTTED LINE TO SLAB THICKNESS "T"

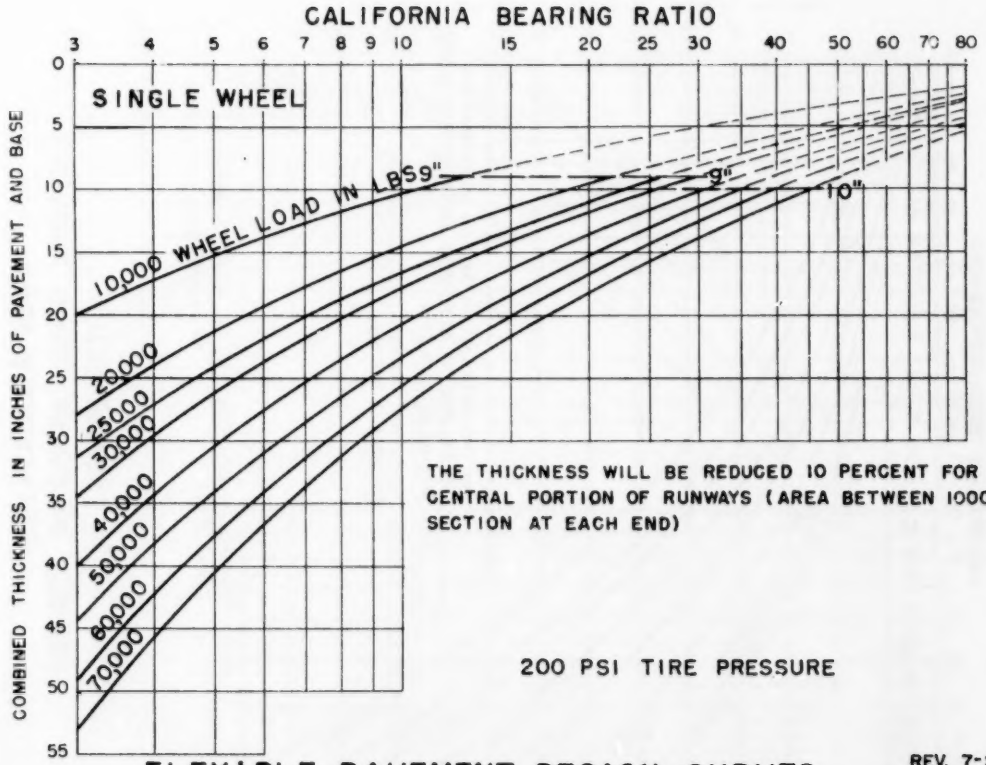
Fig. 5A


CALIFORNIA BEARING RATIO
3 4 5 6 7 8 9 10 15 20 25 30 40 50 60 70 80
0 5 10 15 20 25 30 35 40 45 50 55
COMBINED THICKNESS IN INCHES OF PAVEMENT AND BASE
SINGLE WHEEL
10,000 WHEEL LOAD IN LBS
20,000
25,000
30,000
40,000
50,000
60,000
70,000
8"
9"
THE THICKNESS WILL BE REDUCED 10 PERCENT
CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000FT
SECTION AT EACH END)
100 PSI TIRE PRESSURE

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.

Fig. 1B

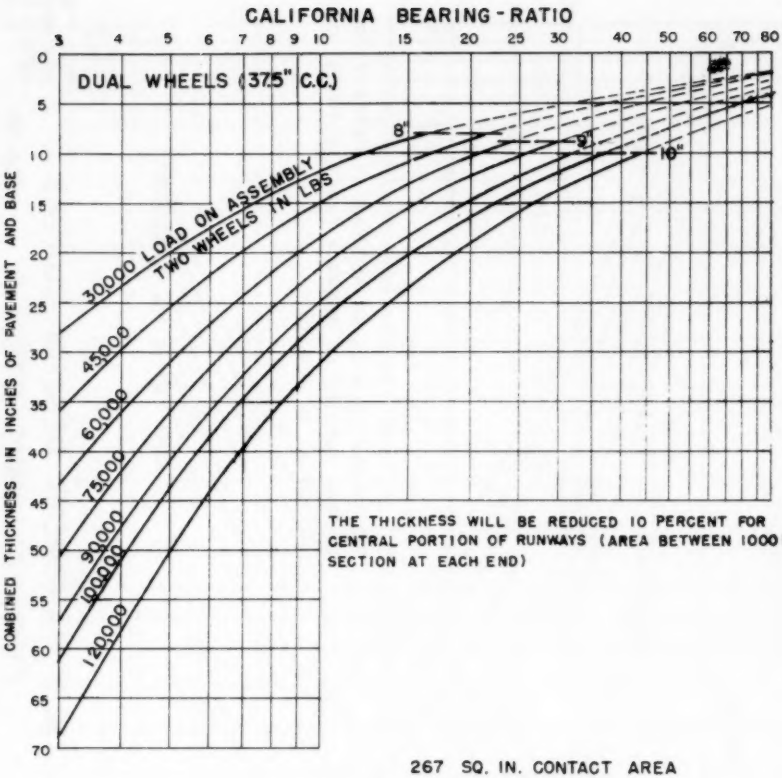
REV. 6-13-50
REV. 3-27-50
8-17-49


CALIFORNIA BEARING RATIO
3 4 5 6 7 8 9 10 15 20 25 30 40 50 60 70 80
0 5 10 15 20 25 30 35 40 45 50 55
COMBINED THICKNESS IN INCHES OF PAVEMENT AND BASE
SINGLE WHEEL
9"
10"
10,000 WHEEL LOAD IN LBS
20,000
25,000
30,000
40,000
50,000
60,000
70,000
THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000FT SECTION AT EACH END)
200 PSI TIRE PRESSURE

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.

Fig. 2B

REV. 7-21-50
REV. 6-13-50
REV. 3-27-50
8-18-49

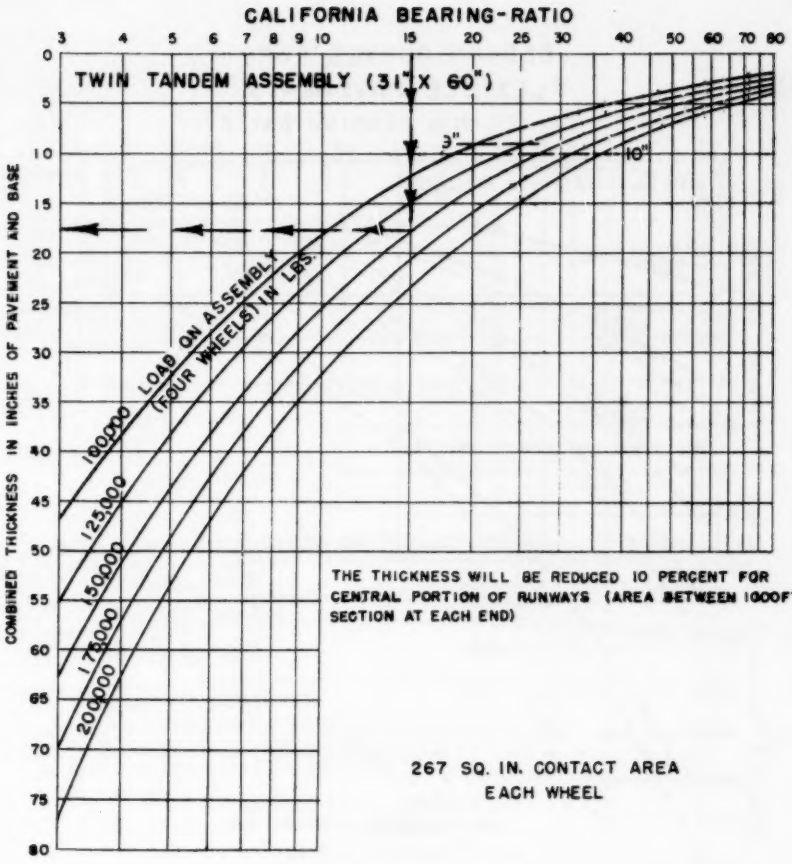

CALIFORNIA BEARING-RATIO
3 4 5 6 7 8 9 10 15 20 25 30 40 50 60 70 80
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
DUAL WHEELS (37.5" C.C.)
COMBINED THICKNESS IN INCHES OF PAVEMENT AND BASE
30000 LOAD ON ASSEMBLY
TWO WHEELS IN LBS
45000
60000
75000
90000
100000
120000
8"
9"
10"
THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 1000 FT SECTION AT EACH END)

267 SQ. IN. CONTACT AREA
EACH WHEEL

(TENTATIVE)
FLEXIBLE PAVEMENT DESIGN CURVES
FOR TAXIWAYS ETC.

REV. 7-21-50
REV. 6-13-50
REV. 3-27-50
8-22-49

Fig. 3B


CALIFORNIA BEARING-RATIO
3 4 5 6 7 8 9 10 15 20 25 30 40 50 60 70 80
TWIN TANDEM ASSEMBLY (31" X 60")
3"
10"
COMBINED THICKNESS IN INCHES OF PAVEMENT AND BASE
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
LOAD ON ASSEMBLY (FOUR WHEELS) IN LBS.
100,000
125,000
150,000
175,000
200,000
THE THICKNESS WILL BE REDUCED 10 PERCENT FOR CENTRAL PORTION OF RUNWAYS (AREA BETWEEN 100FT SECTION AT EACH END)
267 SQ. IN. CONTACT AREA EACH WHEEL

(TENTATIVE)

FLEXIBLE PAVEMENT DESIGN CURVES FOR TAXIWAYS ETC.

REV. 7-21-50
REV. 6-13-50
REV. 3-27-50
8-19-49

Fig. 4B

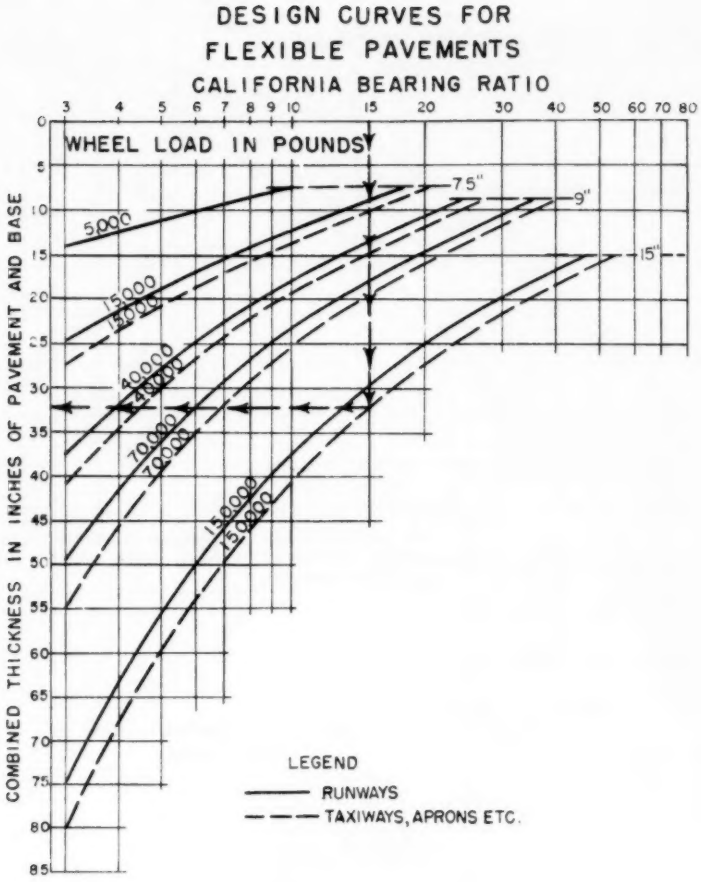
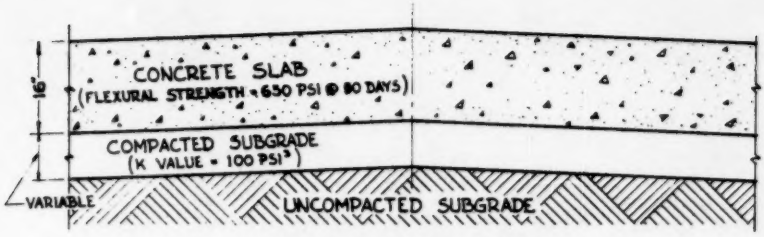
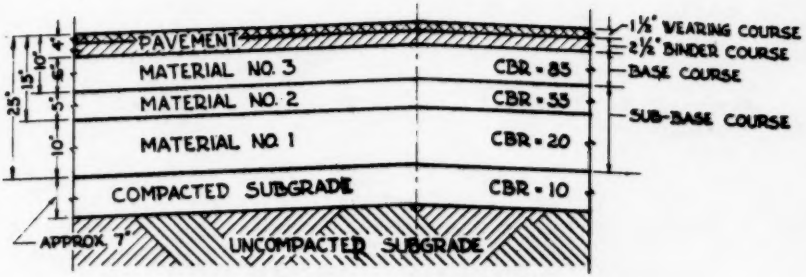

DESIGN CURVES FOR
FLEXIBLE PAVEMENTS
CALIFORNIA BEARING RATIO
3 4 5 6 7 8 9 10 15 20 30 40 50 60 70 80
WHEEL LOAD IN POUNDS
COMBINED THICKNESS IN INCHES OF PAVEMENT AND BASE
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
5,000
15,000
20,000
40,000
50,000
70,000
90,000
135,000
150,000
7.5"
9"
15"
LEGEND
RUNWAYS
TAXIWAYS, APRONS ETC.

Fig. 5B



RIGID PAVEMENT



FLEXIBLE PAVEMENT

TYPICAL CROSS-SECTIONS

Fig. 6

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